CLAIMS

What is claimed is:

1. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network, wherein the fuzzy inference network is trained in order to generate a rule base of fuzzy rules, with each fuzzy rule assigned to a class label, and each fuzzy rule including at least one membership function corresponding to a dimension of the data, with each membership function including membership function parameters, wherein the fuzzy rules are used for classifying input data into memberships, wherein test data with a known classification membership is provided to the fuzzy inference network and wherein the fuzzy inference network uses the fuzzy rules to generate classification memberships for the test data by firing the fuzzy rules with each fuzzy rule fired assigned a firing strength based on its match to the test data, and determining the fuzzy rule having the greatest firing strength, where the membership functions of the rule having the greatest firing strength are compared to the known classification membership of the test data to determine classification error, the improvement comprising:

   a. storing a firing frequency count and incrementing the firing frequency count for each fuzzy rule, indicating the number of times the fuzzy rule has been fired;

   b. determining whether the firing strength of the fuzzy rule having the greatest firing strength exceeds a predetermined threshold;

c. in the case where the firing strength of the fuzzy rule having the greatest firing strength exceeds the threshold, tuning the fuzzy rule based on the classification error; and

d. in the case where the firing strength of the fuzzy rule having the greatest firing strength does not exceed the threshold, determining whether the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data;

i. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength does not correctly match the known classification membership of the test data, tuning the fuzzy rule based on the classification error as in step c; and

ii. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data, applying a learning rule to update the membership function parameters such that the classification error is minimized for high-dimensional classification tasks.

2. A rule base generated by the method of claim 1.

3. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network as

set forth in Claim 1, wherein the tuning step c of the improvement further comprises the sub-steps of:

i. applying a fuzzy similarity measure to compare the membership function along each dimension of the test data with the test data;

ii. adding a new membership function along those dimensions where the fuzzy similarity measure is not satisfied;

iii. creating a new fuzzy rule including the new membership functions and those membership functions that satisfied the fuzzy similarity measure; and

iv. adding the new rule to the rule base.

4. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network as set forth in Claim 3, wherein the tuning step c of the improvement further includes the sub-steps of:

i. assigning a mean value to each new membership function equal to the value of the test data corresponding to the dimension corresponding the respective new membership function;

ii. incrementing the firing frequency count for new fuzzy rule; and

iii. assigning a classification membership to the new fuzzy rule matching the classification membership of the test data for which the rule fired.

5. A rule base generated by the method of Claim 4.

6. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network as set forth in Claim 4, wherein the membership functions are selected from the group consisting of Gaussian membership functions, triangular membership functions, and trapezoidal membership functions.

7. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network as set forth in Claim 4, wherein the membership functions are Gaussian membership functions, and the membership function parameters of each Gaussian membership function include a mean and a variance, and wherein the learning rule applied in the case of step d(ii) updates the mean and variance of the Gaussian membership functions of the fuzzy rule having the greatest firing strength according to:

$$\mu^* = (1 - \frac{|e|}{f})\mu + \frac{|e|}{f}x, \text{ and}$$

$$\sigma^* = \sqrt{(1 - \frac{|e|}{f})\sigma^2 + \frac{|e|}{f}(\sigma - x)^2}, \text{ where}$$

where μ^* represents the updated mean of the Gaussian membership function, σ^* represents the updated variance of the Gaussian membership function,

μ represents the non-updated mean of the Gaussian membership function,

σ represents the non-updated variance of the Gaussian membership function, $|e|$ represents the classification error for the Gaussian membership function, x represents the particular value of the test data for the dimension corresponding to the Gaussian membership function, and f represents the firing frequency for the particular fuzzy rule to which the learning rule is applied.

8. An improved method for generating an on-line learning fuzzy inference network for the classification of data using an on-line learning fuzzy inference network as set forth in Claim 1, the membership functions are Gaussian membership functions, and where the membership function parameters of each Gaussian membership function include a mean and a variance, and wherein the learning rule applied in the case of step d(ii) updates the mean and variance of the Gaussian membership functions of the fuzzy rule having the greatest firing strength according to:

$$\mu^* = (1 - \frac{|e|}{f})\mu + \frac{|e|}{f}x, \text{ and}$$

$$\sigma^* = \sqrt{(1 - \frac{|e|}{f})\sigma^2 + \frac{|e|}{f}(\sigma - x)^2}, \text{ where}$$

where μ^* represents the updated mean of the Gaussian membership function, σ^* represents the updated variance of the Gaussian membership function, μ represents the non-updated mean of the Gaussian membership function, σ represents the non-updated variance of the Gaussian membership function, $|e|$

represents the classification error for the Gaussian membership function, x represents the particular value of the test data for the dimension corresponding to the Gaussian membership function, and f represents the firing frequency for the particular fuzzy rule to which the learning rule is applied.

9. A rule base generated by the method of claim 8.

10. An improved method for generating an on-line learning fuzzy inference network for the classification of data comprising the steps of:

    a. providing an on-line learning fuzzy inference network, wherein the fuzzy inference network generates a rule base of fuzzy rules, with each fuzzy rule assigned to a class label, and each fuzzy rule including at least one membership function corresponding to a dimension of the data, with each membership function including membership function parameters, wherein the fuzzy rules are used for classifying input data into memberships, wherein test data with a known classification membership is provided to the fuzzy inference network and wherein the fuzzy inference network uses the fuzzy rules to generate classification memberships for the test data by firing the fuzzy rules with each fuzzy rule fired assigned a firing strength based on its match to the test data, and determining the fuzzy rule having the greatest firing strength, where the membership functions of the rule having the greatest firing strength are compared to the known classification membership of the test data to determine classification error

and wherein the firing frequency count of each fuzzy rule is stored, the improvement comprising:

b. determining whether the firing strength of the fuzzy rule having the greatest firing strength exceeds a predetermined threshold;

c. in the case where the firing strength of the fuzzy rule having the greatest firing strength exceeds the threshold, tuning the fuzzy rule based on the classification error; and

d. in the case where the firing strength of the fuzzy rule having the greatest firing strength does not exceed the threshold, determining whether the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data;

i. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength does not correctly match the known classification membership of the test data, tuning the fuzzy rule based on the classification error as provided in the case represented by c; and

ii. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data, applying a learning rule to update the membership function parameters such that the classification error is minimized for high-dimensional classification tasks.

11. An improved training system for a fuzzy inference network for on-line classification of data including a fuzzy inference network for generating a rule base of fuzzy rules, with each fuzzy rule assigned to a class label, and each fuzzy rule including at least one membership function corresponding to a dimension of the data, with each membership function including membership function parameters, wherein the fuzzy rules are used for classifying input data into memberships, wherein test data with a known classification membership is provided to the fuzzy inference network and wherein the fuzzy inference network uses the fuzzy rules to generate classification memberships for the test data by firing the fuzzy rules with each fuzzy rule fired assigned a firing strength based on its match to the test data, and determining the fuzzy rule having the greatest firing strength, where the membership functions of the rule having the greatest firing strength are compared to the known classification membership of the test data to determine classification error, the improvement comprising:

a firing frequency count calculated for each fuzzy rule and incremented each time the fuzzy rule is fired, the firing frequency count being stored in the processing device, and a rule tuning and learning rule application processor connected with the fuzzy inference network to receive the fuzzy rules; the classification error; the firing strength, the firing frequency count, and the classification membership generated by for the fuzzy rule having the greatest firing strength; the test data, and the known classification memberships for the test data; said processor

operative for determining whether the firing strength of the fuzzy rule having the greatest firing strength exceeds a predetermined threshold; and

a. in the case where the firing strength of the fuzzy rule having the greatest firing strength exceeds the threshold, tuning the fuzzy rule based on the classification error; and

b. in the case where the firing strength of the fuzzy rule having the greatest firing strength does not exceed the threshold, determining whether the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data;

i. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength does not correctly match the known classification membership of the test data, tuning the fuzzy rule based on the classification error; and

ii. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data, applying a learning rule to update the membership function parameters such that the classification error is minimized for high-dimensional classification tasks.

12. A rule base generated by the training system of claim 11.

13. An improved training system for a fuzzy inference network for on-line classification of data as set forth in Claim 11, wherein the rule tuning and learning rule application processor is further operative to:

a. apply a fuzzy similarity measure to compare the membership function along each dimension of the test data with the test data;

b. add a new membership function along those dimensions where the fuzzy similarity measure is not satisfied;

c. create a new fuzzy rule including the new membership functions and those membership functions that satisfied the fuzzy similarity measure; and

d. add the new rule to the rule base.

14. An improved training system for a fuzzy inference network for on-line classification of data as set forth in Claim 13, wherein the rule tuning and learning rule application processor is further operative to:

a. assign a mean value to each new membership function equal to the value of the test data corresponding to the dimension corresponding the respective new membership function;

b. increment the firing frequency count for new fuzzy rule; and

c. assign a classification membership to the new fuzzy rule matching the classification membership of the test data for which the rule fired.

15. An improved training system for a fuzzy inference network for on-line classification of data as set forth in Claim 14, wherein the membership functions

are selected from the group consisting of Gaussian membership functions, triangular membership functions, and trapezoidal membership functions.

16. An improved training system for a fuzzy inference network for on-line classification of data as set forth in Claim 14, wherein the membership functions are Gaussian membership functions, and the membership function parameters of each Gaussian membership function include a mean and a variance, and wherein the learning rule applied updates the mean and variance of the Gaussian membership functions of the fuzzy rule having the greatest firing strength according to:

$$\mu^* = (1 - \frac{|e|}{f})\mu + \frac{|e|}{f}x, \text{ and}$$

$$\sigma^* = \sqrt{(1 - \frac{|e|}{f})\sigma^2 + \frac{|e|}{f}(\sigma - x)^2}, \text{ where}$$

where μ^* represents the updated mean of the Gaussian membership function, σ^* represents the updated variance of the Gaussian membership function, μ represents the non-updated mean of the Gaussian membership function, σ represents the non-updated variance of the Gaussian membership function, $|e|$ represents the classification error for the Gaussian membership function, x represents the particular value of the test data for the dimension corresponding to the Gaussian membership function, and f represents the firing frequency for the particular fuzzy rule to which the learning rule is applied.

17. An improved training system for a fuzzy inference network for on-line classification of data as set forth in Claim 11, wherein the membership functions are Gaussian membership functions, and where the membership function parameters of each Gaussian membership function include a mean and a variance, and wherein the learning rule updates the mean and variance of the Gaussian membership functions of the fuzzy rule having the greatest firing strength according to:

$$\mu^* = (1 - \frac{|e|}{f})\mu + \frac{|e|}{f}x, \text{ and}$$

$$\sigma^* = \sqrt{(1 - \frac{|e|}{f})\sigma^2 + \frac{|e|}{f}(\sigma - x)^2}, \text{ where}$$

where μ^* represents the updated mean of the Gaussian membership function, σ^* represents the updated variance of the Gaussian membership function, μ represents the non-updated mean of the Gaussian membership function, σ represents the non-updated variance of the Gaussian membership function, $|e|$ represents the classification error for the Gaussian membership function, x represents the particular value of the test data for the dimension corresponding to the Gaussian membership function, and f represents the firing frequency for the particular fuzzy rule to which the learning rule is applied.

18. A rule base generated by the training system of claim 17.

19. An improved training system for a fuzzy inference network for on-line classification of data comprising:

a. an on-line learning fuzzy inference network wherein the fuzzy inference network generates a rule base of fuzzy rules, with each fuzzy rule assigned to a class label, and each fuzzy rule including at least one membership function corresponding to a dimension of the data, with each membership function including membership function parameters, wherein the fuzzy rules are used for classifying input data into memberships, wherein test data with a known classification membership is provided to the fuzzy inference network and wherein the fuzzy inference network uses the fuzzy rules to generate classification memberships for the test data by firing the fuzzy rules with each fuzzy rule fired assigned a firing strength based on its match to the test data, and determining the fuzzy rule having the greatest firing strength, where the membership functions of the rule having the greatest firing strength are compared to the known classification membership of the test data to determine classification error and wherein the firing frequency count of each fuzzy rule is stored;

b. a rule tuning and learning rule application processor connected with the fuzzy inference network to receive the fuzzy rules; the classification error; the firing strength, the firing frequency count, and the classification membership generated by the fuzzy rule having the greatest firing strength; the test data, and the known classification memberships for the

test data; said processor operative for determining whether the firing strength of the fuzzy rule having the greatest firing strength exceeds a predetermined threshold; and

i. in the case where the firing strength of the fuzzy rule having the greatest firing strength exceeds the threshold, tuning the fuzzy rule based on the classification error; and

ii. in the case where the firing strength of the fuzzy rule having the greatest firing strength does not exceed the threshold, determining whether the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data;

a. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength does not correctly match the known classification membership of the test data, tuning the fuzzy rule based on the classification error; and

b. in the case where the classification membership generated by the fuzzy rule having the greatest firing strength correctly matches the known classification membership of the test data, applying a learning rule to update the membership function parameters such that the classification error is minimized for high-dimensional classification tasks.